CLASSIC EXPOSURES OF THE ANASTASIA FORMATION IN MARTIN AND PALM BEACH COUNTIES, FLORIDA

Miami Geological Society Field Trip
Saturday, November 7, 1998

Field Trip Leader

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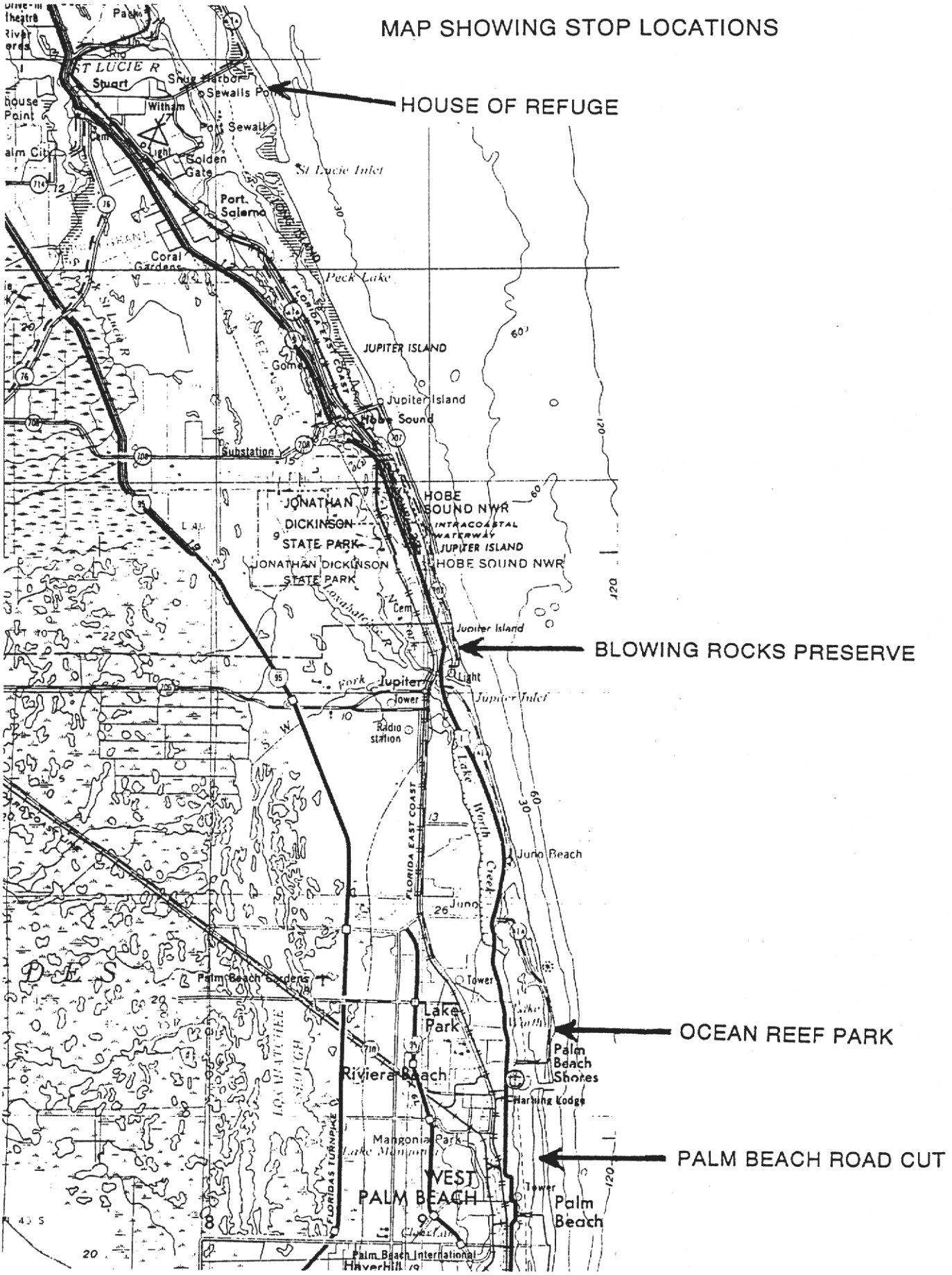
FIELD TRIP SCHEDULE

8:00 AM	Depart Chapel-by-the-Lake parking lot, opposite the First Baptist Church on Flagler Drive, just south of Okeechobee Boulevard in downtown West Palm Beach.
8:15 AM	STOP #1. PALM BEACH ROAD CUT, Palm Beach.
8:45 AM	Depart Palm Beach Road Cut.
9:00 AM	STOP #2. OCEAN REEF PARK, Singer Island. Opportunity for snorkeling, coffee break.
10:00 AM	Depart Ocean Reef Park.
10:30 AM	STOP #3. BLOWING ROCKS PRESERVE, Jupiter Island.
12:00 AM	Depart Blowing Rocks Preserve. LUNCH STOP. CORAL COVE PARK, Jupiter Island.
2:00 PM	STOP #4. HOUSE OF REFUGE, Stuart. Abbreviated Visit: follow outcrop for one-half mile northward from House of Refuge. Extended Visit: drive 0.8 miles south to a beach access where the outcrop begins and follow it for 1.3 miles northward.
4:00 PM	Field Trip ends.


MAP SHOWING STOP LOCATIONS
HOUSE OF REFUGE
BLOWING ROCKS PRESERVE
OCEAN REEF PARK
PALM BEACH ROAD CUT
Stuart
Sewalls Point
Port Salerno
St Lucie Inlet
Peck Lake
JUPITER ISLAND
Jupiter Island
Hobe Sound
JONATHAN DICKINSON STATE PARK
HOBE SOUND NWR
INTRACOASTAL WATERWAY
Jupiter Inlet
Lake Worth
Juno Beach
Palm Beach Gardens
Lake Park
Riviera Beach
Palm Beach Shores
Mangonia Park
WEST PALM BEACH
Palm Beach
Palm Beach International
FLORIDA EAST COAST
FLORIDAS TURNPIKE

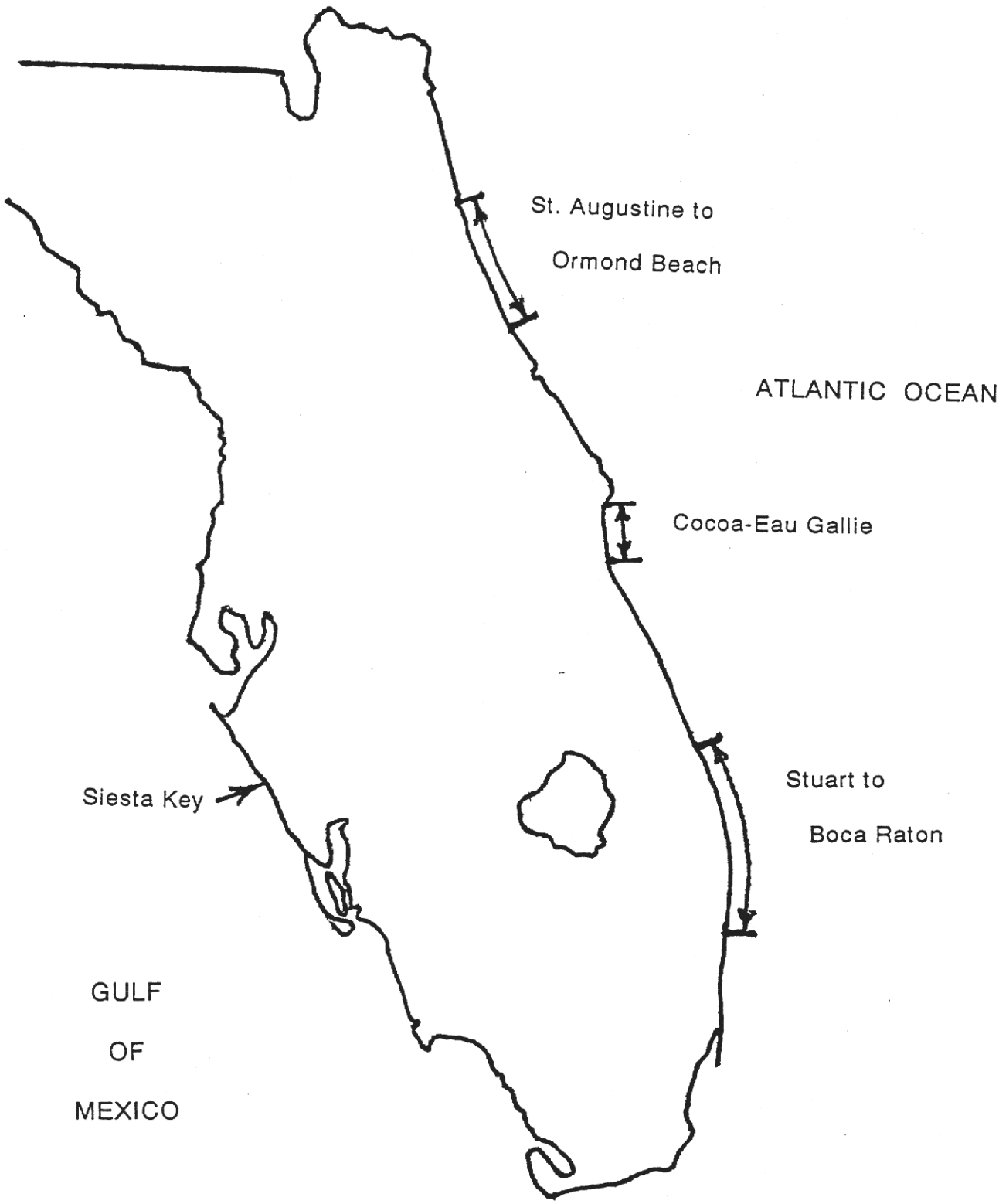


Figure 1a. **Map of Florida showing location of major outcrop areas of the Anastasia Formation.**

INTRODUCTION

The Anastasia Formation is a Late Pleistocene coquinoid limestone that is exposed at intervals along the coastal zone of Martin and Palm Beach Counties. This guidebook will introduce the reader to the most frequently visited exposures and to the highlights of the area geology. The shoreline of these two counties consists of long barrier islands and sandy beaches, which are separated from the mainland by the Intracoastal Waterway. Exposures of the Anastasia Formation are found along the ocean, on the barrier islands, and in the Intracoastal Waterway.

This guidebook is designed for a one-day field trip involving about 50 people. Rather than visiting all the significant exposures, four stops have been selected to illustrate the main features of the Anastasia Formation and to stimulate discussion of the formation's depositional environment and subsequent history. Included as an appendix to the text is a list of additional stops for those having both time and desire to see some of the lesser known exposures of the formation.

Throughout the trip special emphasis will be placed on depositional features of the formation, such as its lithology, stratification, and fossil contents, as well as post-depositional aspects such as bioturbation, laminated crusts, solution features, lithified infillings, and wave erosion features. Participants in the field trip will be encouraged to speculate about the environment in which the Anastasia might have been deposited and lithified, and what the Anastasia tells us about past sea level changes in the area.

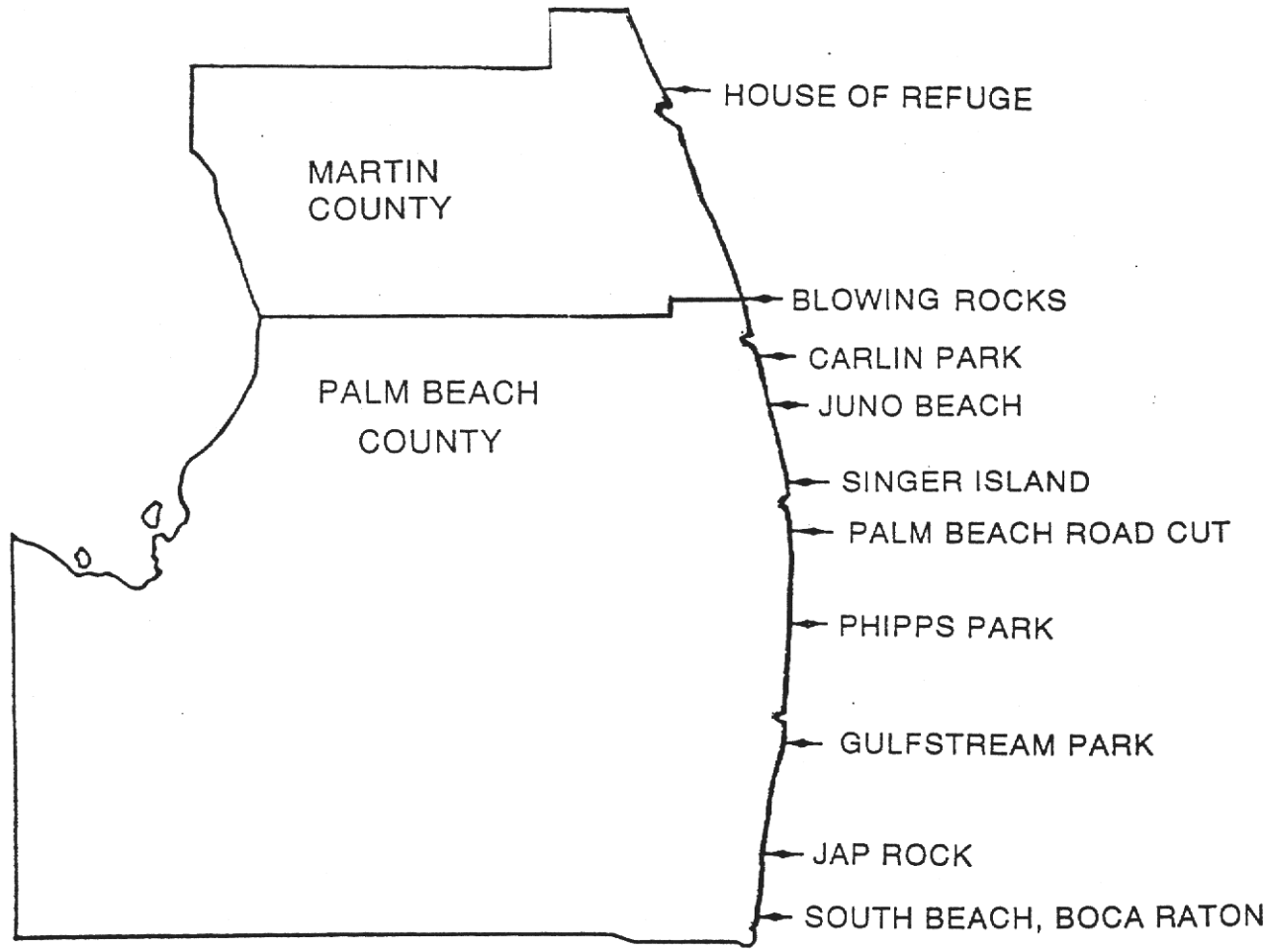


Figure 1b. **Map showing location of major outcrops of the Anastasia Formation in Martin and Palm Beach Counties.**

GENERAL FEATURES OF THE ANASTASIA FORMATION

Along Florida's east coast the Anastasia Formation crops out in a narrow belt extending from Anastasia Island in St. Johns County on the north (the type locality) to Boca Raton in Palm Beach County on the south, a distance of more than 320 km (Sellards, 1912; Puri, 1964; Vernon and Puri, 1964; Brooks, 1982). Excellent exposures appear in three areas: (1) St. Augustine south to Ormond Beach, (2) Cocoa south to Eau Gallie, and (3) Stuart south to Boca Raton. On Florida's west coast the only significant exposure of coquina is a 1 km-long outcrop at Point of Rocks on Siesta Key in Sarasota County. This guidebook deals with the outcrops along Florida's lower east coast, from Stuart south to Boca Raton (Fig. 1a and 1b).

South of Boca Raton the Anastasia Formation grades into the Miami Limestone, which has been dated as 130,000 years old (Halley and Evans, 1983; Evans and Ginsburg, 1987). McNeill (1985) estimates the age of the Anastasia Formation to be 130,000 to 100,000 years old. Perkins (1977) states that the Anastasia is the youngest lithified marine Pleistocene deposit found in the coastal areas of Florida. Inland it is believed to grade into a shell-in-quartz-sand facies with thin discontinuous limestone beds. Parker and others (1955) state that the thickness of the Anastasia Formation may exceed 30 m in some places. It is overlain by unconsolidated quartz sand, mud, or peat.

Lithology

The Anastasia Formation in Martin and Palm Beach Counties is a variably sandy, coquinoid limestone (Johnson, 1989). The rock is white- to tan-colored on a freshly exposed surface and weathers to shades of gray and brown. When first cut, the rock is quite soft, but upon exposure to the atmosphere its surface becomes casehardened, making possible the development of cliffs in many outcrop areas.

The rock is a mixture of shell fragments and quartz grains bound together by calcium carbonate cement. Cooke (1945) reports that iron oxide cement is occasionally present. The coquina varies from a coarse-grained limestone composed entirely of broken shell fragments to a sandstone composed of carbonate and quartz sand grains. Heavy mineral grains and discoidal pebbles of coquina rock are also present. The sand grains and the heavy minerals probably came from the Carolinas and Georgia, but the shell fragments and the coquina rock pebbles are believed to have originated locally.

Quartz grains in the coquina vary from fine to coarse sand-size and are angular and poorly sorted. Shell fragments in the coquina consist of variably abraded skeletal carbonate debris which may take one of the following forms:

(1) sand-size shell fragments mixed with quartz grains to produce a rock with a granular texture resembling that of sandstone,

(2) shell hash layers composed of shell fragments up to 2.5 cm long; few, if any, quartz grains present; often poorly sorted,

(3) whole or broken shells up to 7.5 cm long on bedding planes; these are thought to have been left behind by the winnowing action of waves and currents,

(4) occasional intact megafossils 20 cm or more in length.

Stratification

The Anastasia Formation may display planar bedding, with the individual layers parallel to the main planes of stratification in the rock, or cross-bedding in which the individual layers are inclined at an oblique angle to the main planes of stratification in the rock. On smooth surfaces the bedding may give the rock a banded appearance, but on deeply weathered surfaces, the rock may have a ribbed appearance, with resistant layers standing out as ridges and the less resistant layers indented as grooves (Fig.2).

Bedding in the Anastasia Formation is caused by one or more of the following factors:

(1) differences in grain size from one layer to another,

(2) differences in composition between one layer and another, particularly as to the amount of shell material present,

(3) varying degrees of cementation from one layer to another,

(4) color differences between layers, usually due to the presence of shell material or iron staining, and

(5) shell fragments lying oriented with their longest dimensions parallel to the depositional surface.

At several localities the Anastasia Formation is noticeably cross-bedded, with both herringbone and avalanche cross-bedding being present. Herringbone cross-bedding occurs when the oblique layers are inclined first in one direction and then in the opposite direction, giving the rock a herringbone appearance when viewed in cross-section (Fig. 3). This type of cross-bedding may have been produced by shifting current directions, such as tidal currents in the littoral zone. Avalanche cross-bedding results when all the oblique layers dip uniformly in the same direction (Fig. 4). This type of cross-bedding is characteristic of water-laid sediments and the oblique layers dip in the direction that the current was moving. Halley and Evans (1983) describe this type of cross-bedding from the Miami Limestone and believe it was formed by the avalanching of sand grains down the slip faces of advancing sand waves.

Fossil Contents

Coquinoid limestones generally consist of macerated shell debris, but the Anastasia Formation also contains intact shells of several common, thick-shelled mollusks (Fig. 5 and Fig. 6). Fragments of molluscan shells are present in all outcrops, although the size of the fragments in the southerly outcrops is generally no larger than sand size. From Palm Beach northward the size increases, however, and intact shells become more common, possibly due to the widening of continental shelf. Not only would a wider continental shelf have supported a larger mollusk population, but it would have acted as a buffer for the more destructive storm waves.

The shell fragments found in the Anastasia Formation are invariably worn and polished by wave abrasion, often being reduced to flat plates with rounded edges. Such abrasion must have taken place in a high-energy environment, and this could have been found on the crests of offshore bars. Offshore bars extend seaward 200-300 m from the Martin and Palm Beach County coasts today, and waves can be seen breaking over them when the surf is high, creating conspicuous foam lines. The crests of these bars are 6-9 m wide and they are located in 1-2 m of water at low tide. High-energy conditions also occur in the breaker zone along the beach. This zone contains the so-called "wave mill" --an area of coarse shell

Figure 2. Bedded coquina with large burrows, House of Refuge.

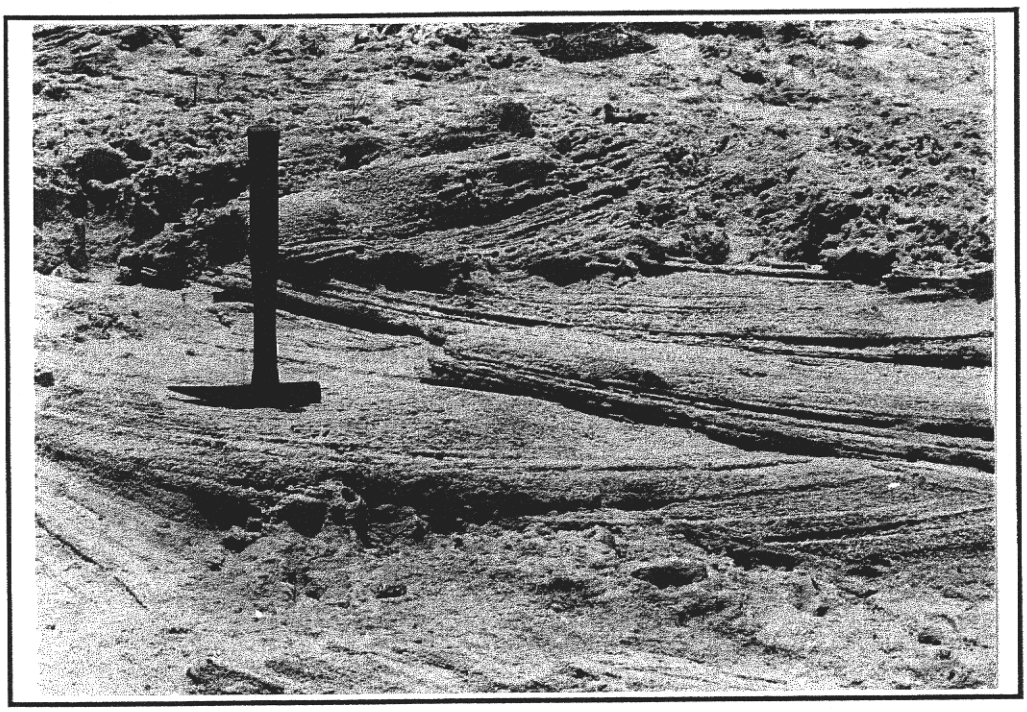


Figure 3. Herringbone cross-bedding in Anastasia Formation, south of Gulfstream Park.

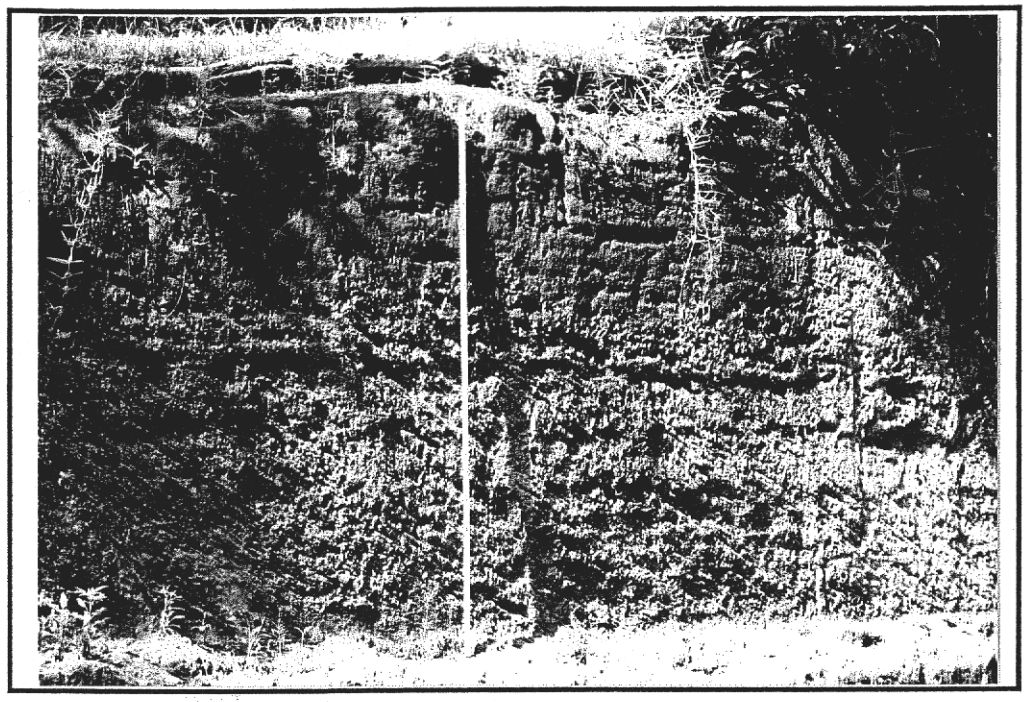


Figure 4. Avalanche cross-bedding, Palm Beach Road Cut. Stick is 1.8 m high. Horizontal markings were made during excavation of road cut.

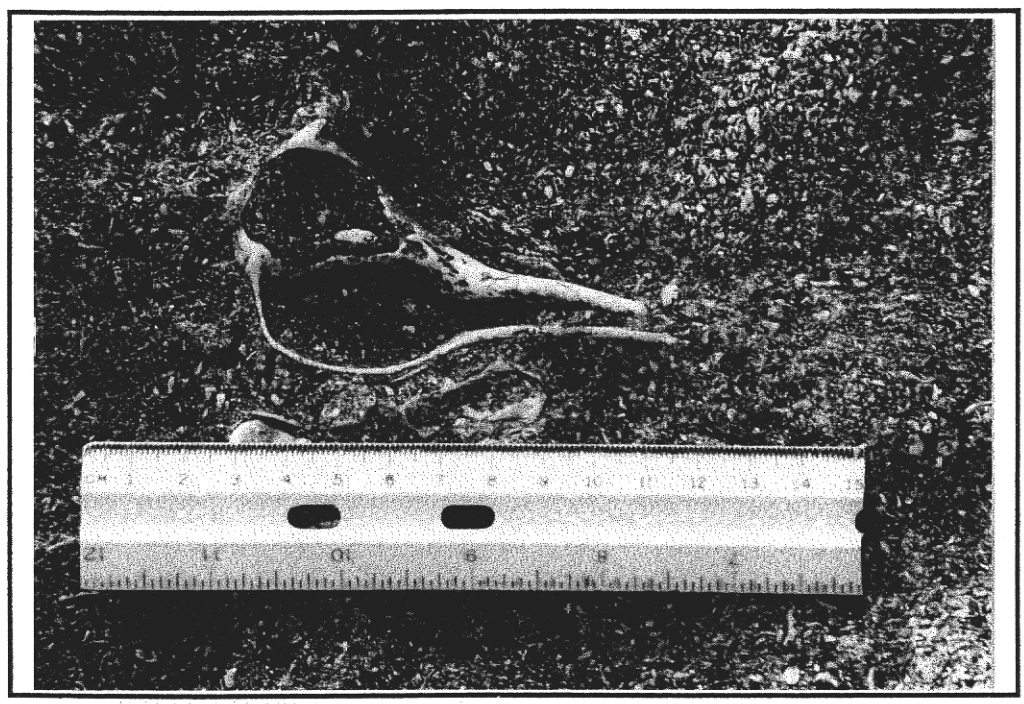


Figure 5. Busycon contrarium, a common thick-shelled gastropod in the Anastasia Formation.

debris found at the lower, or seaward margin of the beach. Wave action causes shell fragments to slide back and forth in this zone, rubbing against each other with a rustling sound, and fragments of coquinoid limestone are shaped into discoidal pebbled known as "shingles" in this zone.

The best locality in Martin and Palm Beach Counties for finding intact shells in the Anastasia Formation is at Blowing Rocks Preserve in southern Martin County. Here a prominent sea cliff follows the shoreline for a distance of 1.6 km, exposing a thickness of 2-4 m of coquina. Mollusks that have been observed in the coquinoid limestone at Blowing Rocks include:

Anadara sp.
Busycon contrarium
Chione cancellata
Crassostrea virginica
Crepidula fornicata
Dinocardium robustum
Donax variabilis
Glycymeris americanus
Mercenaria mercenaria
Noetia ponderosa
Oliva sp.
Pecten ziczac

Non-molluscan material present in the Anastasia includes a scutellid sand dollar and a fragment of Little Star Coral (Montastrea annularis). The bony shell of a turtle could formerly be seen in the rock at the House of Refuge (Fig. 7) but is no longer present. The only other vertebrate remain known from the Anastasia Formation is a small limb bone found in the coquina at Bulow Plantation in the northeastern part of the state.

The molluscan fauna of the Anastasia Formation contains extant forms that inhabit the sandy bottom just offshore from the beach today (Morris, 1973). Most of these organisms have thick and sturdy shells that would resist prolonged abrasion. Donax variabilis, the so-called "coquina" shell from which the rock type draws its name, is the most common fossil in east-central and northeastern Florida outcrops of the Anastasia, but it is rarely found in Martin and Palm Beach Counties because southeast Florida is at the southern end of Donax's geographic range.

Another aspect of the Anastasia fauna in southeast Florida is that intact Mercenaria shells do not appear in the outcrops, although broken fragments of these shells are commonplace. This is puzzling because Mercenaria has the sturdiest shell of all the Anastasia mollusks. Possibly the thick Mercenaria shells were attacked after the organism's death by borers such as sponges and polychaete worms, which would have contributed to the rapid breakdown of the shells.

Microfossils are present in the offshore zone of Martin and Palm Beach Counties today and include foraminifera, radiolaria, molts from crustaceans, and fragments of fish bones, shark teeth and crab claws. None of these have been identified in outcrops of the coquina although Cole (1931) reports seven species of foraminifera from outcrops of the coquina in Nassau County.

Bioturbation

Except for the outcrop at Phipps Park, all of the localities where the Anastasia Formation is exposed in Palm Beach and Martin Counties display tubular structures that are inferred to represent fossilized animal burrows (Lovejoy, 1987). These burrows are particularly well developed at Ocean Reef Park on Singer Island, at the Blowing Rocks Preserve in southern Martin County, and at the House of Refuge near Stuart.

These presumed burrows fall into two distinct categories, designated herein as small and large burrows. The small burrows are found at the crests of outcrops and are generally closely spaced. Many of them extend downward 2 m or more. They have roughly circular cross sections 1-2.5 cm in diameter and may be straight, curved or irregular. The burrow lining is smooth, but the exterior is knobby. The burrow walls are mud-lined and the interiors are hollow or filled by coquinoid limestone. Because of the hardened wall linings, the burrows stand out in sharp relief, giving the upper surface of the outcrops a cratered appearance (Fig. 8). On the sides of the outcrops, the burrows resemble interwoven rods (Fig. 9). Burrows may branch at acute angles, and enlargements at or between bifurcations are frequent.

The burrows in the second category are designated as large burrows. These are found primarily at the base of the outcrops (Fig. 10) and are widely spaced, with circular to oval cross sections as much as 5 cm in diameter. The diameter of these burrows may increase and decrease irregularly, giving them a nodular appearance. The interiors of these burrows are filled by coquinoid limestone, and they may also stand out from the rock in bold relief.

The organisms that formed these burrows have not been fossilized so that their identity is purely conjectural. It is assumed that at least two types of organisms were involved, presumably both crustaceans. Callianassa sp. has been held responsible for small burrows in the Miami Limestone similar to those in the Anastasia Formation (Halley and Evans, 1983). Such burrows are often referred to as the trace fossil Ophiomorpha sp.

Shinn (1986) has pointed out that the Miami Limestone affords an opportunity to compare preserved Pleistocene burrows with those that are in the process of being built today, and the same can be said of the Anastasia Formation in Martin and Palm Beach Counties. Not only are the fossil burrows exceptionally well preserved at Ocean Reef Park, Blowing Rocks, and the House of Refuge, but the burrowed limestone is composed of the same materials that compose the beach and near-shore zone today. Burrowing organisms are present in the beach and near-shore zone, but to date no research has been done comparing their burrows with the fossil burrows found in the adjoining Anastasia outcrops.

Structures similar to these presumed burrows have been called "fossil roots" at Mangrove Reef in Miami by Hoffmeister and Multer (1964) and at various South Florida locations by Perkins (1977). The interpretation seems a reasonable one for Mangrove Reef in view of the sheltered location of the outcrop and the presence of live mangroves growing nearby. However, the Anastasia Formation is believed to have formed in a high-energy environment, which would not have been conducive to mangrove or other plant growth. The tubular structures in the Anastasia Formation also differ from fossilized root networks in the following ways:

(1) they do not taper downward, as would be expected of roots,

(2) they do not subdivide downward into smaller tubes as roots might be expected to do, and

(3) they have knobby exteriors, oval cross sections, and mud linings, none of which is typical of fossilized roots.

Laminated Crusts

Laminated calcium carbonate crusts (also known as caliche, calcrete, and soilstone) are present on the surface of most outcrops of the Anastasia Formation (Fig. 11). These crusts are relatively thin, averaging 2.5 cm thick, and are noticeably undulating, following the surface of the rock down into solution pits and holes (Fig. 12). Individual laminae are on the order of 1 mm thick and are made up of alternating white and reddish-brown layers. The upper surface of the crusts is typically reddish brown and very smooth.

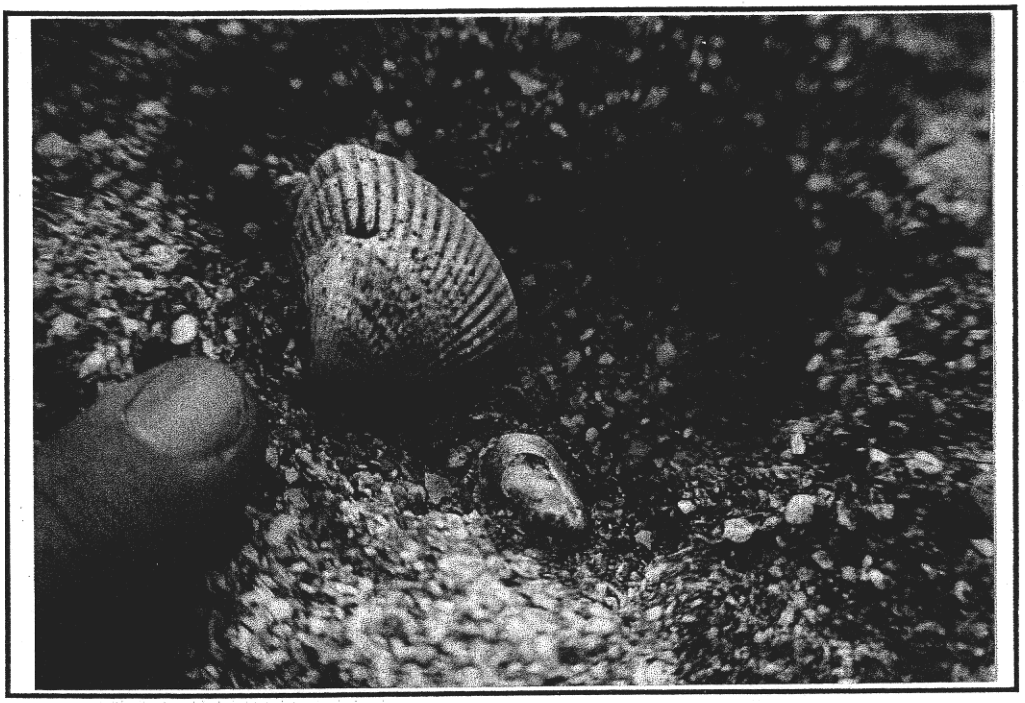


Figure 6. Noetia ponderosa, a thick-shelled bivalve in the Anastasia Formation.

Figure 7. Fossil turtle shell in Anastasia Formation at the House of Refuge.

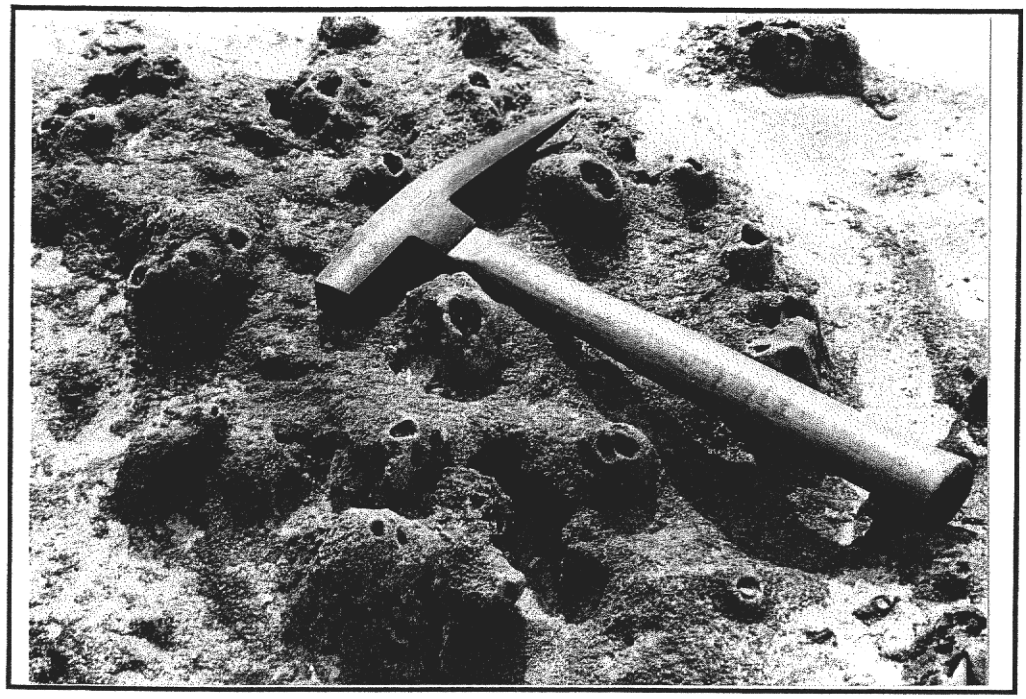


Figure 8. Small burrows on upper surface of outcrop, showing mud linings. Ocean Reef Park, Singer Island.

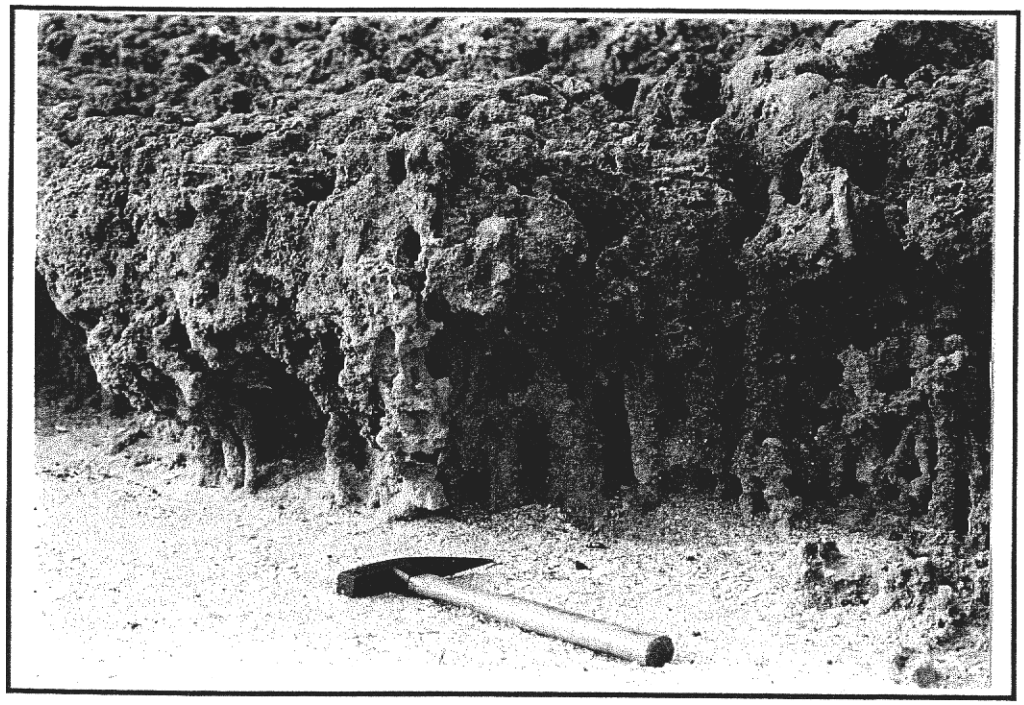


Figure 9. Small burrows on side of outcrop, Blowing Rocks Preserve, Jupiter.

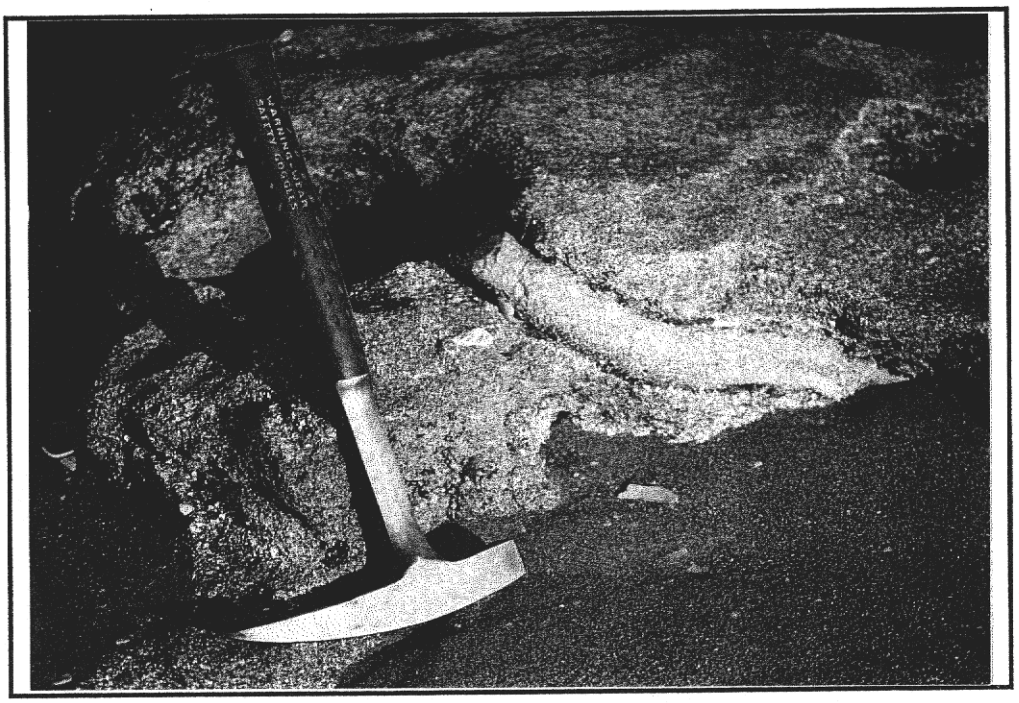


Figure 10. Large burrow at base of outcrop, Coral Cove Park, Jupiter.

Figure 11. Laminated calcrete crust on upper surface of Anastasia Formation, House of Refuge.

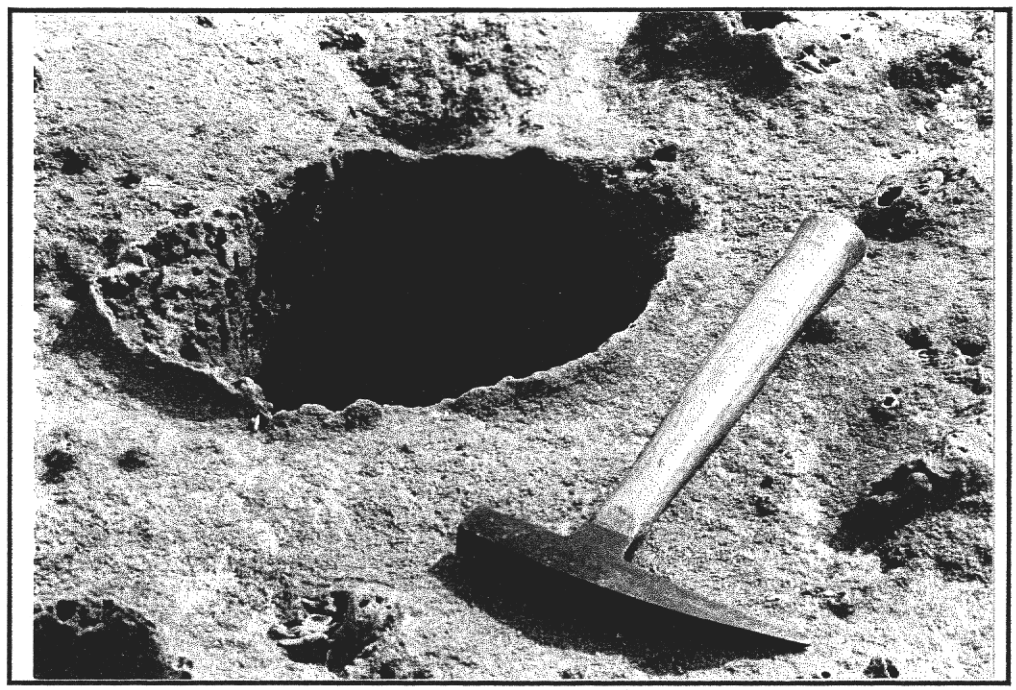


Figure 12. Calcrete crust extending down into solution hole, Ocean Reef Park, Singer Island.

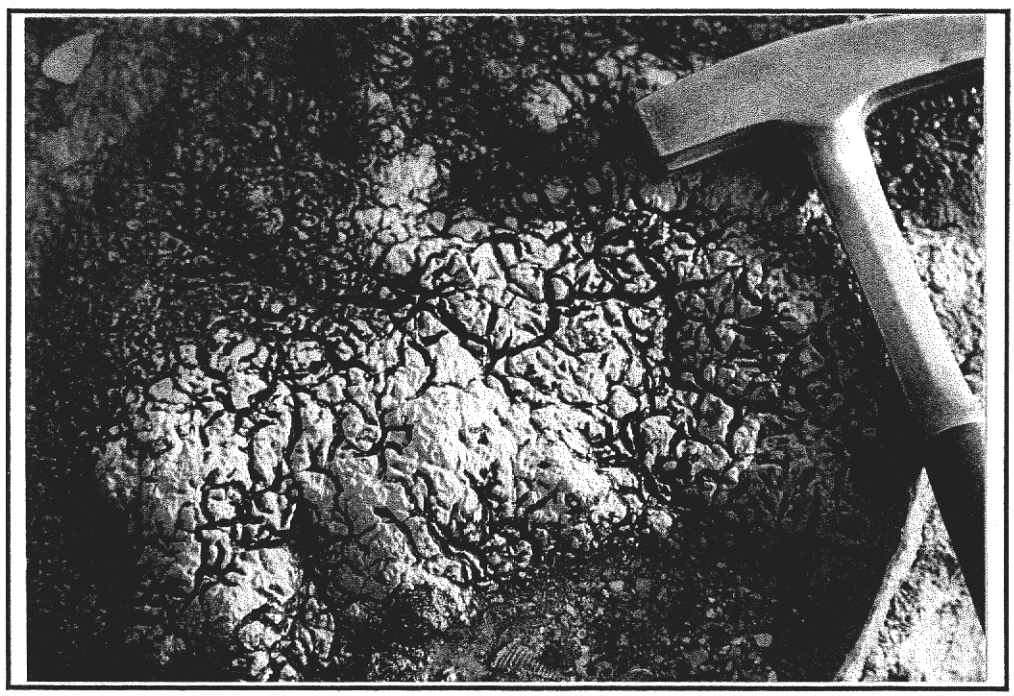


Figure 13. Root impressions on surface of laminated crust, Blowing Rocks Preserve.

Robbin and Stipp (1979) and Lidz and Shinn (1991) have described such crusts from the Florida Keys and conclude that they formed in a subaerial environment by leaching and reprecipitation of calcium carbonate beneath a thin layer of peaty soil; the brown color is attributed to included organic matter and minute traces of iron. A similar origin has been postulated for the crusts on the Anastasia Formation (Perkins, 1977).

At Blowing Rocks Preserve in southern Martin County, surface features on the laminated crusts include presumed root impressions and botryoidal growths. The root impressions consist of branching grooves with a dendritic pattern (Fig. 13). These appear to be impressions left by roots in soil overlying the growing crusts. The botryoidal growths are rounded knobs resembling clusters of grapes (Fig. 14). These probably formed when radiating aggregates of calcium carbonate crystals grew in supersaturated waters that filled low places on the impervious crusts.

Solution Features

Two kinds of solution features are present in the Anastasia Formation: surface pits, which produce intersecting shallow depressions on the surface of coquina outcrops (Fig. 15), and holes >1 m deep that have been described as "solution pipes" by Perkins (1977). The surface pits are believed to have been formed by acidic water standing on the surface of the rock, whereas downward percolation probably played a role in the formation of the solution pipes. Both features can have perfectly circular outlines and remarkably smooth surfaces, presumably due to modification by wave abrasion (Fig. 16). If the pipes are open at their bottoms due to the presence of a notch, they may act as "blow holes" when the surf in high (Fig. 17). Blowing Rocks derives its name from such features. Solution pipes that are closed at the bottom may be filled by sediment which becomes subsequently lithified.

Lithified Infillings

As just indicated, solution pipes in the Anastasia Formation may be frequently filled by loose material which subsequently becomes partially or completely lithified by calcium carbonate cement to form lithified infillings. The filling may consist of sand grains, pieces of coral, shingle pebbles, and even an occasional bottle fragment. When identifiable shells are present in the infillings, it is important not to mistake them for original fossil contents of the rock.

The lithified infillings are readily distinguishable because their lithology is completely different from that of the surrounding rock. In several places the infillings are more thoroughly cemented than the Anastasia itself, with the result that they project above the rock surface as small-scale positive relief features 15 cm or more high (Fig. 18). Similar knobs have been reported from the Anastasia Formation at Washington Oaks State Gardens in Flagler County by Meeder and others (1981).

Wave Erosion Features

Coastal outcrops of the Anastasia Formation display many geomorphic features typical of wave-erosion coasts. Sea cliffs are present if a sufficient thickness of coquina is exposed. These cliffs may have conspicuous notches at their base and occasionally a small sea cave. Rock promontories may jut outward with small coves in between. At the base of the promontories erosion may have carved miniature sea arches (Fig. 19). Where masses of bedrock have fallen forward from the cliffs they may form small sea stacks. A wave abrasion platform is also present at the base of most cliffs, although it may be covered by a thin layer of loose sand much of the year.

A severe extratropical storm on October 30 and November 1, 1991 provided opportunities for observing at firsthand the process of cliff retreat along the Martin and Palm Beach County coasts. This storm generated swell waves 6 m high that pounded the coastal cliffs for three days. During this time many large masses of bedrock broke off the coastal cliffs and fell forward into the surf zone where wave abrasion is now attacking them (Fig. 20).

The major factor involved in the collapse of these bedrock masses was the presence of a deeply indented notch at the base of the cliffs (Fig. 21). This notch makes the overhanging bedrock highly vulnerable to wave attack. The origin of these notches is probably due to a combination of the following processes:

(1) wave abrasion in the surf zone,

(2) weaknesses in the rock due to horizontal stratification,

(3) pressures set up in the rock by the growth of salt crystals upon drying,

(4) dissolving of the rock by rainwater, salt spray, sea water, or ground water emerging at the base of the cliffs, and

(5) biological erosion caused by marine organisms living in the intertidal zone.

Depositional Environment

Previous workers have speculated about the environment in which the Anastasia Formation was deposited (Cooke, 1945; Brooks, 1972; Murphy, 1973; Meeder and others, 1981; McNeill, 1983 and 1985; Lovejoy, 1987). Although most workers favor a high-energy depositional environment for the Anastasia, the tubular structures would suggest low-energy conditions if they are fossilized mangrove roots. If the tubular structures represent fossilized animal burrows, then either high-energy or low-energy conditions could be indicated (Frey and others, 1978).

Evidence for high-energy conditions during the deposition of the Anastasia Formation would include:

(1) the sand size of the shell fragments,

(2) the known habitat of most of the Anastasia fauna,

(3) the heavily abraded shell fragments, and

(4) the absence of intact foraminifera or micromollusks.

High energy conditions are found along the Martin and Palm Beach County coasts today at the offshore bars and along the beach. Evidence favoring an offshore bar origin for the coquina is found in outcrops where the strata are oppositely inclined on both sides of the same exposure, suggesting the contours of an offshore bar (McNeill, 1985; Lovejoy, 1987). Evidence for a beach origin would be the size distribution of the grains in the rock, which is almost identical with the size distribution of the grains found in modern beaches along Florida's east coast (McNeill, 1985).

Results of a study recently conducted by the Palm Beach County Department of Environmental Resource Management showed that some offshore bars are composed entirely of fine to medium quartz sand, with more than 95% of the grains being less than 0.5 mm in diameter; coarser sand and shell fragments were encountered only nearer the beach (personal communication, P. Mikkelsen). This data points to a beach origin for the Anastasia Formation.

Figure 14. Botryoidal growths on surface of laminated crust, Blowing Rocks Preserve.

Figure 15. Solution pitting on surface of outcrop, Ocean Reef Park.

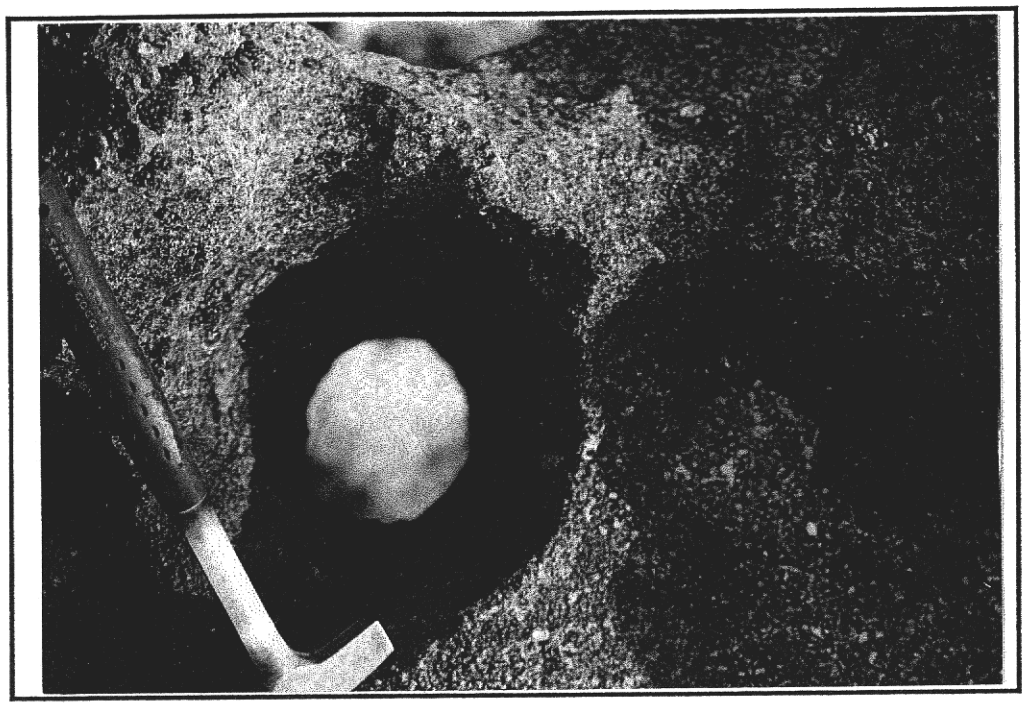


Figure 16. Wave-abraded solution pipe forming "blow hole" at Coral Cove Park, Jupiter.

Figure 17. Water spouts up through "blow hole" at Blowing Rocks when the surf is high.

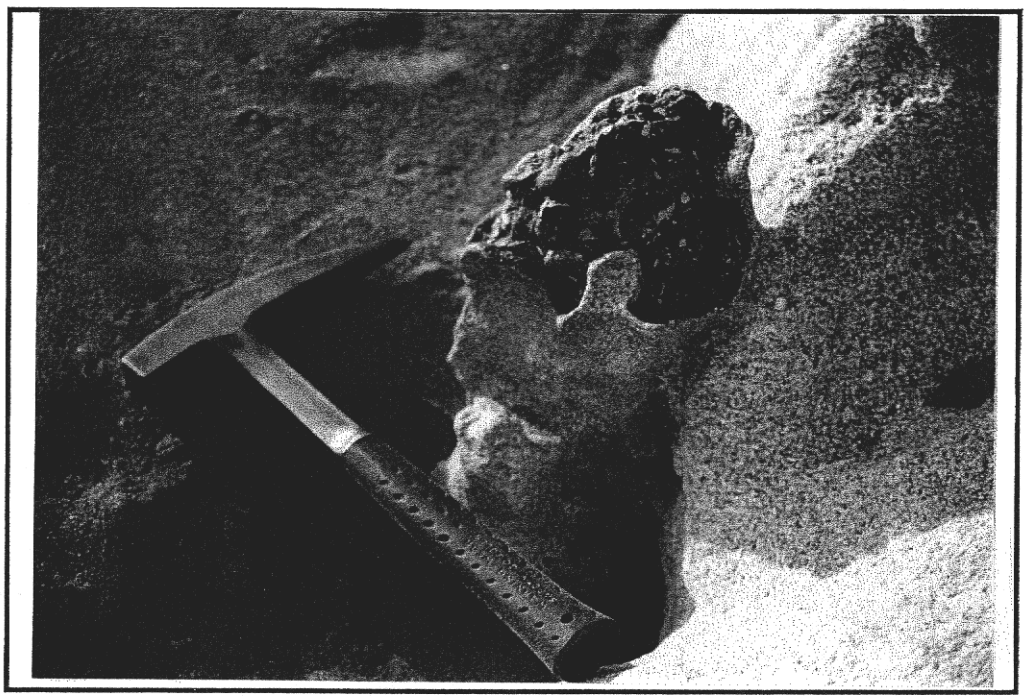


Figure 18. Lithified infilling of solution pipe projecting as positive relief feature, Carlin Park.

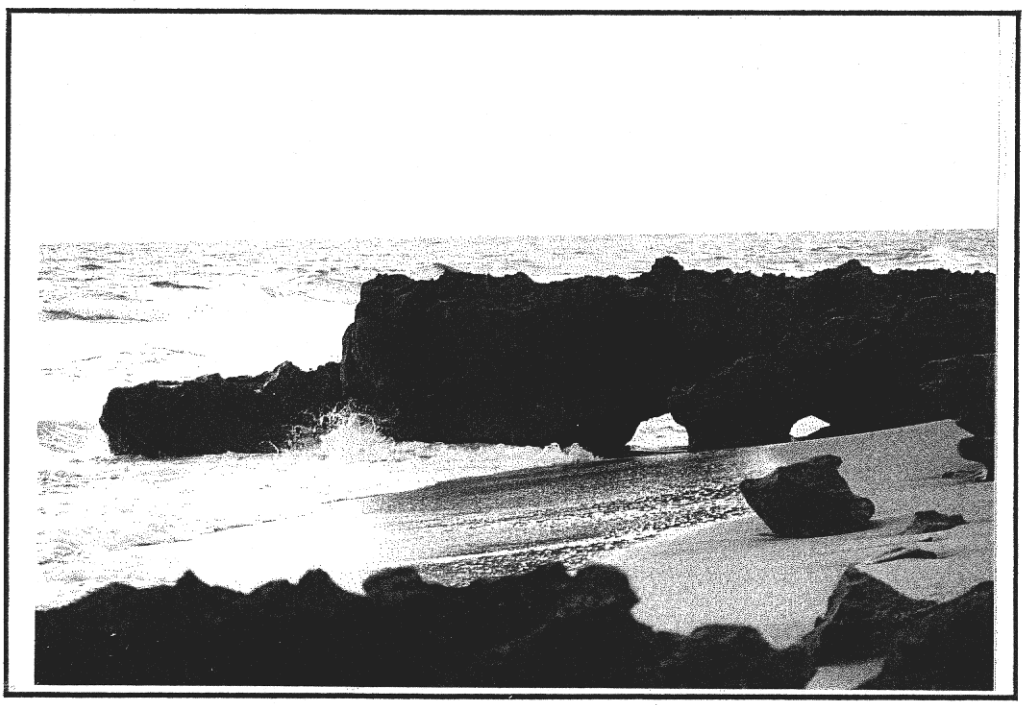


Figure 19. Double sea arch in coquina outcrop, Coral Cove Park.

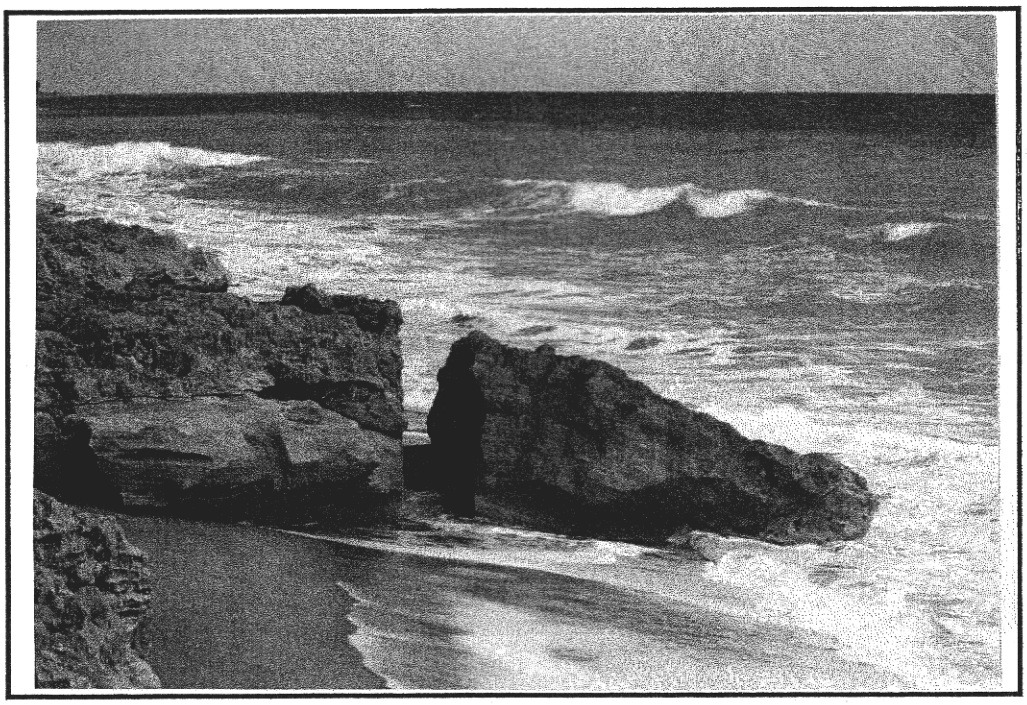


Figure 20. Large mass of collapsed rock, Blowing Rocks Preserve.

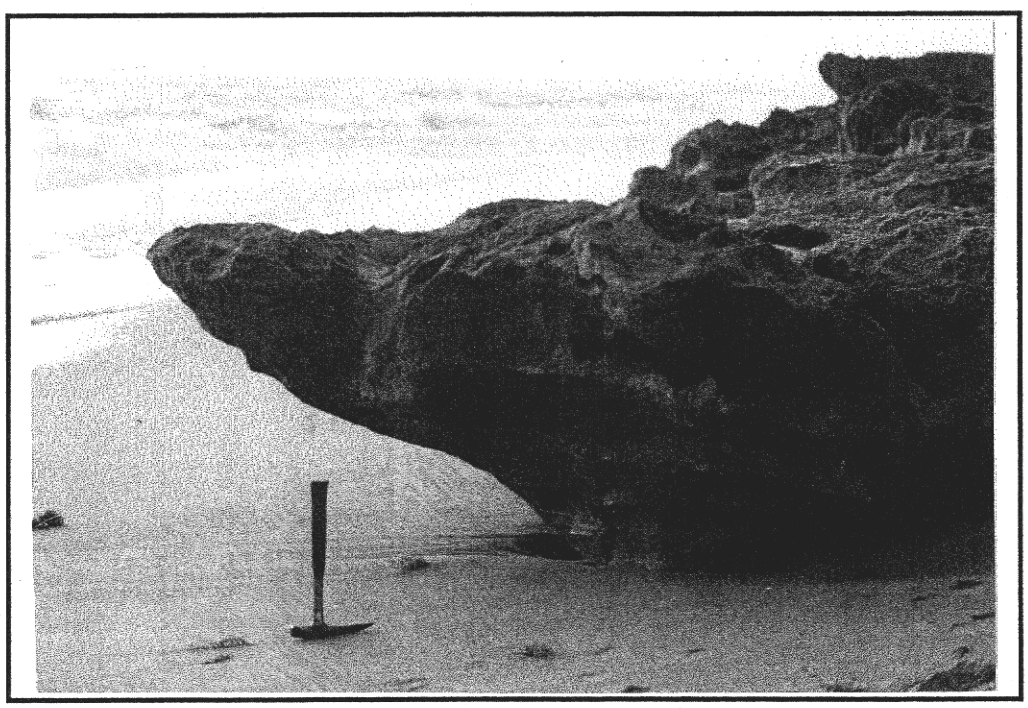


Figure 21. Deeply indented notch at base of sea cliff, House of Refuge.

Lithification

The exact nature of the processes that lithified the Anastasia Formation are not fully known. One possibility is that the Anastasia Formation represents an ancient beachrock, and that cementation took place in the tidal zone when sea water evaporated as it drained through the beach at low tide. A second possibility is that the Anastasia Formation formed above sea level through the dissolution and reprecipitation of calcium carbonate by circulating meteoric waters. Because beachrock forms only on tropical coasts, and the only known occurrence of it in the continental United States is in the Dry Tortugas islands off Key West (Ginsburg, 1953), it is assumed that the Anastasia Formation was lithified by the second method. The Anastasia Formation could be an ancient beachrock only if tropical waters had extended as far north as St. Augustine during interglacial times.

Sea Level Changes

The Anastasia Formation provides clues regarding sea level changes along the Martin and Palm Beach County coasts during the Pleistocene and Quaternary. At the time the Anastasia was deposited, 130,000 - 100,000 years ago, the earth was experiencing an interglacial age. Glaciers and the polar ice had melted back, resulting in a world-wide rise in sea level of 6 m or more above the present height. Most of Martin and Palm Beach Counties were underwater, which would account for the shells found inland as well as the low hills that represent old barrier beach/dune deposits (Perkins, 1977). These hills crest at an elevation of 25 m above sea level in Jonathan Dickinson State Park at Hobe Sound.

Subsequently the earth entered the final glacial age, and sea level fell as ice reformed and the oceans chilled. The barrier beach/dune deposits found in Jonathan Dickinson State Park and elsewhere became inland hills, and new barrier beach/dune deposits formed farther seaward as sea level retreated. Eventually thin soils developed on these new barrier beach/dune deposits and scrub vegetation took hold. As acidic rain percolated downward through the sand, it leached calcium carbonate from the shells which was then redeposited as cement to hold the grains together. In this way the coquina rock we call the Anastasia Formation was formed. Sediments containing little or no shell material were not cemented and still remain as loose sand. Where the newly formed coquina was covered by peaty soil, calcium carbonate crusts built up on the coquina's surface.

Finally global temperatures began to return to normal and sea level started its long, slow rise. As sea level reached its present height, outcrops of the Anastasia Formation began to undergo wave erosion in the surf zone. The outcrops that still remain submerged form offshore reefs (Swavely, 1971). These reefs consist of bedrock ledges with varying amounts of live and dead coral, and are separated by intervals of barren, sandy bottom. The reefs are found at successively deeper intervals down to depths of 33 m and extending 1.6 km out from shore southward of the Palm Beach inlet. Northward of the inlet the reefs extend farther seaward but have been less well explored; in fact, Swavely disappeared here during a dive to 84 m (275 feet) about 5 km from shore on January, 12, 1992.

ROAD LOG AND STOP DESCRIPTIONS

Total Mileage	
	Meet at the parking lot of the Chapel-by-the-Lake in downtown West Palm Beach, just south of the intersection of Okeechobee Boulevard and Flagler Drive. (Use Okeechobee East Exit from I-95).
0.0	Cross Flagler Bridge and proceed north on South County Road to Country Club Road.
3.4	Turn left on Country Club Road and park along curb before the first intersection.
3.6	STOP #1. PALM BEACH ROAD CUT Caution: walk facing the traffic; the road cut is very narrow. The road cut extends 600 feet westward and has rock walls about 20 feet high on both sides (Fig. 22). The rock is a granular coquina resembling sandstone on the east and grades into a fine-grained shell hash at the west end. At the east end avalanche cross-bedding dips 31° W., and midway through the road cut the bedding undulates from horizontal to dips of 31° W. A scour-and-fill structure is also present, truncating the cross-bedding beneath it. Within the scour-and-fill structure avalanche cross- bedding dips 27° W. Perkins (1977) describes this exposure and has several photographs. He interprets it as a barrier beach deposit on the west separated from a dune deposit on the east by a regional disconformity marked by a paleosoil. Parker and others (1955) called the surface an unconformity. Small burrows are present in this exposure as well as tubular structures at the top of the outcrop that Perkins (1977) called "root casts". These may also represent large burrows.
6.3	Return to U.S. 1. Proceed north on U.S. 1 to Blue Heron Boulevard in Riviera Beach.
11.0	Turn right on Blue Heron Boulevard and proceed 2 miles on A1A to Ocean Reef Park.
13.0	STOP #2. OCEAN REEF PARK The park has restrooms, showers, and an attractive shaded picnic area with tables and outdoor grills. A boardwalk leads to the beach. The Anastasia Formation begins as a reef exposed at low tide 50 yards to the right of the boardwalk and 100 yards offshore. (The reef is an excellent snorkeling area). The outcrop resumes 200 yards north of the boardwalk as a low cliff that extends along the beach for 0.4 miles. Watch for avalanche and herringbone cross-bedding, the cratered upper surface of the coquina due to the presence of many small burrows, large burrows, laminated calcium carbonate crusts, lithified infillings, conspicuous solution pits and notches, and rock masses that have collapsed from the cliff. Continue north along A1A until it intersects U.S. 1
17.4	Turn right on U.S. 1 and proceed north. Cross Jupiter Inlet, marked by red lighthouse to the right, atop an old Indian shell mound.
25.3	Take first right-hand turn after inlet onto Route C-707. Proceed east to Blowing Rocks Preserve.

27.7 STOP #3. BLOWING ROCKS PRESERVE
(If parking lot is full, leave cars at Coral Cove Park 1 mile south).

The Anastasia Formation extends along the shoreline for 1 mile, with cliffs up to 15 feet high. Perkins (1977) mentions this outcrop briefly on his page 157. Note the planar bedding, numerous fossils (faunal list on page 11 of this guidebook), small and large burrows, laminated crusts with root impressions and botryoidal growths, lithified infillings, solution pipes forming "blow holes", notched cliffs and sea caves, promontories and coves, abrasion platform, and large masses of collapsed rock.

Retrace route 1 mile south to Coral Cove Park.

28.8 LUNCH STOP. CORAL COVE PARK
The park has restrooms, showers, and a shaded picnic area. A boardwalk leads to the beach where there is a small, fossiliferous outcrop of the Anastasia with planar bedding, small and large burrows, laminated calcium carbonate crusts, lithified infillings, solution pipes, notched cliffs and sea caves, a double sea arch, and large masses of collapsed rock.

Retrace route 1.4 miles to U.S. 1.

30.2 Turn right on U.S. 1 to Stuart. (The Road Log continues to Stuart via U.S. 1 which is the most direct route.)

49.2 Turn right after large shopping center at sign for A1A.

49.5 Cross railroad tracks. Bear right, following sign to "Hutchinson Island".

51.2 Turn right on East Ocean Boulevard at stoplight.

52.2 Cross St. Lucie River.

53.2 Cross Indian River.

54.1 Turn right at stoplight into Indian River Plantation.

55.4 Park at House of Refuge for Abbreviated Visit.

56.2 Park at beach access for Extended Visit.

STOP #4. HOUSE OF REFUGE (Extended Visit)
The beach access has restrooms and showers, but no picnic tables. A boardwalk leads to the beach.

The Anastasia Formation extends for 2 miles north along the shoreline with cliffs up to 15 feet high at the House of Refuge.

Looking south from the end of the boardwalk we can just see the well-known Bathtub Reef, a popular swimming area for children sheltered by a wormrock reef (Phragmatopoma caudata). Immediately ahead of us is an outcrop with small burrows, laminated crusts, solution pipes, a notch and an abrasion platform, and a mass of collapsed rock. As we proceed up the beach toward the House of Refuge, we will pass

several outcrops with conspicuous notches. At the House of Refuge are prominent planar bedding, many fossils including Busycon, small and large burrows, thick laminated calcium carbonate crusts, lithified infillings, solution pipes, notched cliffs, promontories and small coves, and many large masses of collapsed bedrock.

END OF FIELD TRIP

Retrace route to Stuart. Continue straight ahead on East Ocean Boulevard until you reach Confusion Corner, where you will pick up a sign for Route 76 that will lead you to I-95.

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APPENDIX

Major Outcrops of the Anastasia Formation in Martin and Palm Beach Counties (Locations shown in Fig. 1b)

1. House of Refuge, 2.1 km (1.3 mi) south of Hwy A1A at the south end of Hutchinson Island, Stuart: outcrop extends for 2.1 km (1.3 mi) along shoreline. For description see Field Trip Stop #4.

2. Blowing Rocks Preserve, on Hwy A1A just north of Martin County line; outcrop extends for 1.6 km (1.0 mi) along shoreline. For description see Field Trip Stop #3. A smaller, but similar outcrop is found 1.6 km (1.0 mi) to the south at Coral Cove Park, formerly known as Little Blowing Rocks. For description see Field Trip Lunch Stop.

3. Carlin Park, on Hwy A1A 1.6 km (1.0 mi) south of Jupiter Inlet; fossiliferous outcrops extend northward along beach for 0.8 km (0.5 mi). Planar bedding, large burrows, laminated calcium carbonate crusts, solution pipes, lithified infillings, notches and a small arch.

4. Juno Beach, outcrops extend along beach for 1.6 km (1.0 mi) southward from Celestial Way, Iron oxide cement, planar bedding, small and large burrows, laminated crusts with botryoidal growths, lithified infillings, solution pits and pipes, notches, small sea caves and arches.

5. Ocean Reef Park, 1.6 km (1.0 mi) north of Blue Heron Bridge on Hwy A1A at the south end of Singer Island in Riviera Beach; the outcrop begins as an offshore reef and continues northward as low cliffs for 0.6 km (0.4 mi). For description see field Trip Stop #2.

6. Palm Beach Road Cut, west end of Country Club Road in Palm Beach; outcrop extends for 180 m (600 ft) on both sides of roadway. For description see Field Trip Stop #1.

7. Phipps Park, on Hwy A1A south of Sloan's Curve at south end of Palm Beach; discontinuous outcrops in surf zone extend 8 km (5 mi) southward from the park. Poorly defined planar bedding with prominent east-west trending vertical joints, producing roughly square slabs resembling pieces of highway pavement (Fig. 23). The local residents are convinced that these slabs are remnants of Hwy A1A that were washed into the ocean by a hurricane years ago.

8. Gulfstream Park, on Hwy A1A just north of Gulf Stream town limits; outcrops extend for 0.6 km (0.4 mi) along shoreline south of park. Planar bedding, avalanche and herringbone cross-bedding, small and large burrows, laminated calcium carbonate crusts, notched cliff, and an extensive development of sea caves now filled by cement.

9. Jap Rock, on Hwy A1A at south end of Highland Beach; discontinuous outcrops and ledges in the surf zone extend for 2.7 km (1.7 mi) northward from Jap Rock along the beach. Planar bedding, avalanche and herringbone cross-bedding, small and large burrows, laminated calcium carbonate crusts, lithified infillings, solution pits, and low notched cliffs.

10. South Beach, on Hwy A1A at the south end of Boca Raton; ledges in the surf zone and a larger outcrop extend 0.5 km (0.3 mi) southward from parking area. Planar bedding and herringbone cross-bedding, small and large burrows, solution pits, and a collapsed rock mass.

Minor Outcrops of the Anastasia Formation

In addition to the major outcrops listed above, minor outcrops of the Anastasia Formation are present along beaches, on the barrier islands, and in the Intracoastal Waterway. The most extensive of the Waterway outcrops are found on the shores of the Bingham Islands and on Munyon Island. Beach outcrops are present at John D. MacArthur State Park on Singer Island and at Red Reef Park in Boca Raton. On the barrier islands small outcrops are present on both sides of Highway A1A in Boynton Beach and Delray Beach, and along North Lake Way in Palm Beach.

Note: The amount of exposure at all shoreline outcrops will depend on the height of the tide and the amount of recent sand deposition.

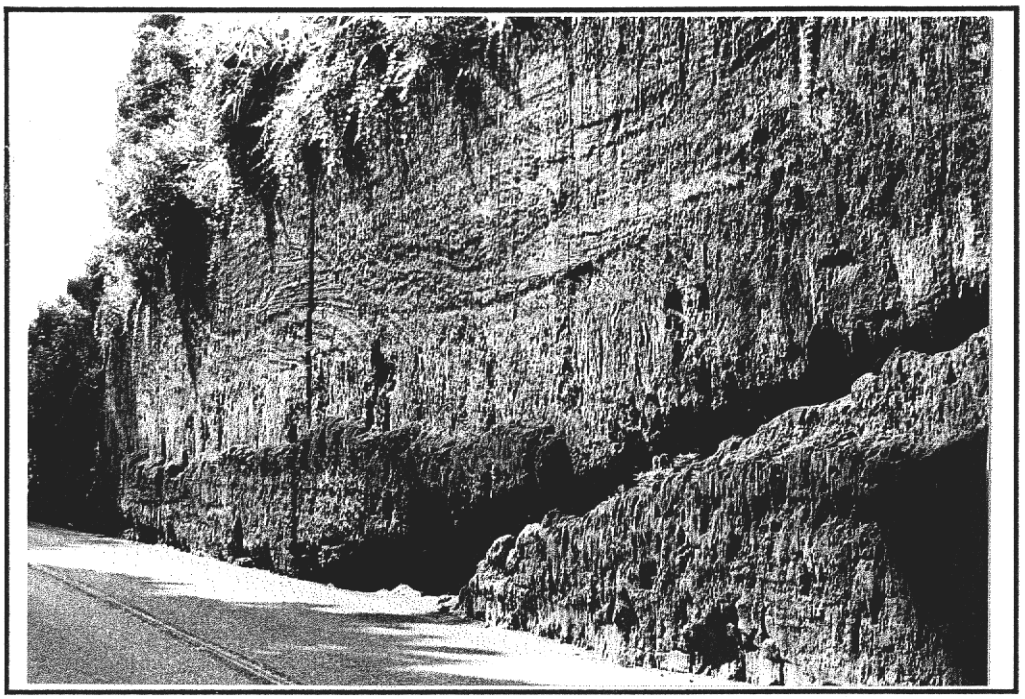

Figure 22. Undulating cross-bedding and disconformity, Palm Beach Road Cut.

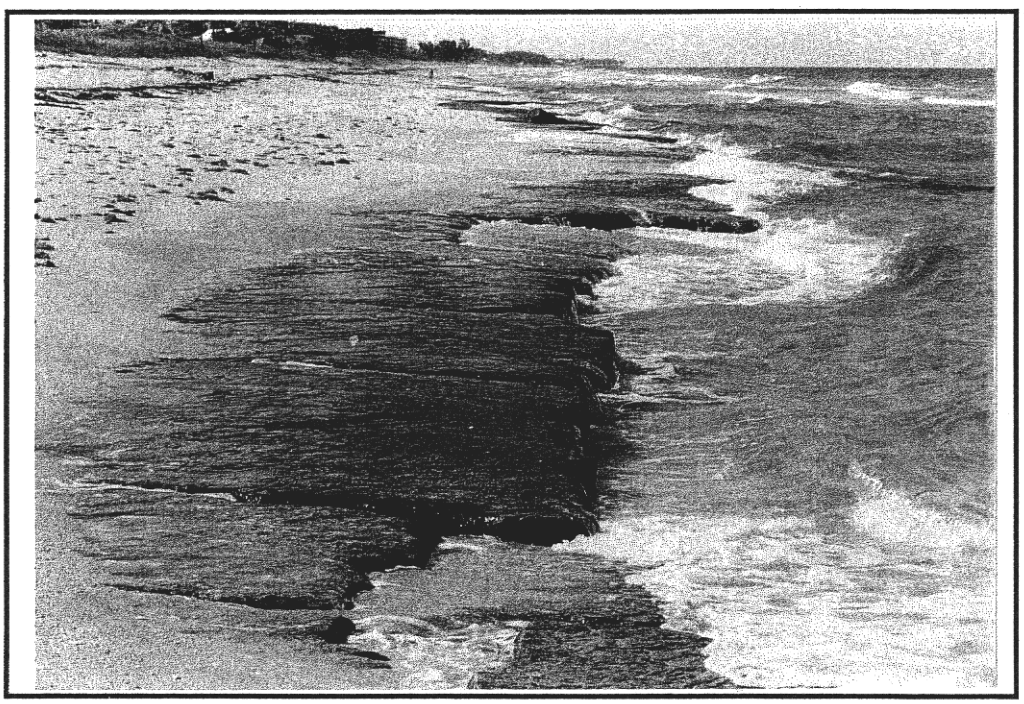

Figure 23. Coquina slabs bounded by bedding planes and vertical east-west joints, south of Phipps Park.